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(54) Method of reducing the dependence of the air gap energy on gap length in a magnetic circuit and apparatus using the method

(57) To reduce the dependence of air gap energy changes in a magnetic circuit (13, 23) with an air gap, the magnet or induction field (H) is refracted at the marginal areas of the air gap in order to change its alignment in the air gap. This is achieved by an oblique positioning of the marginal areas of the air gap defining poles (A, B, A'), for example by designing them with teeth (21, 25). In this way a pronounced independence of the energy change in the air gap per air gap width change is achieved, so that the magnetic device can be used independently of the air gap width at the moment, for example as a force generator which may include an armature.

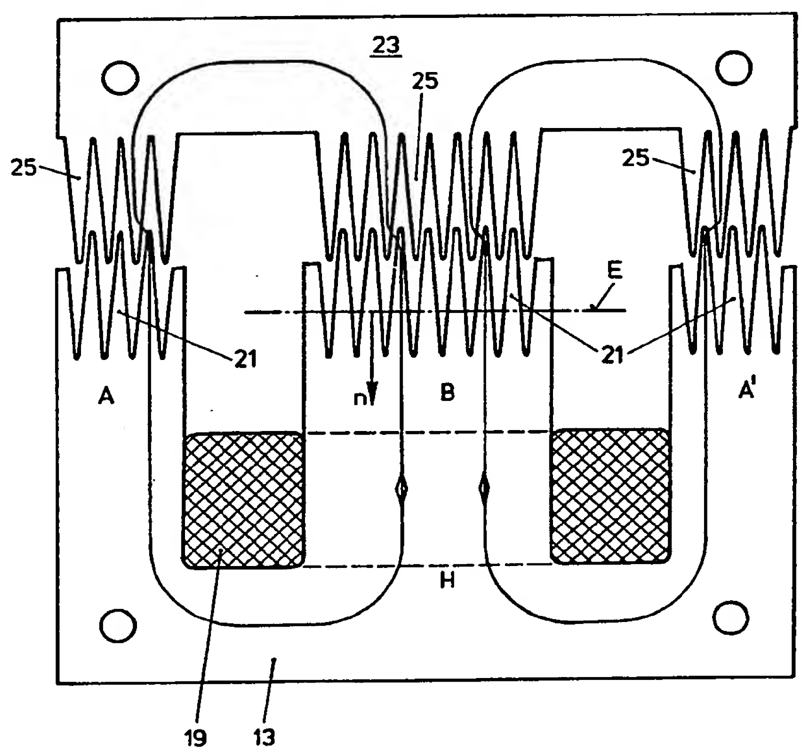

FIG. 3b

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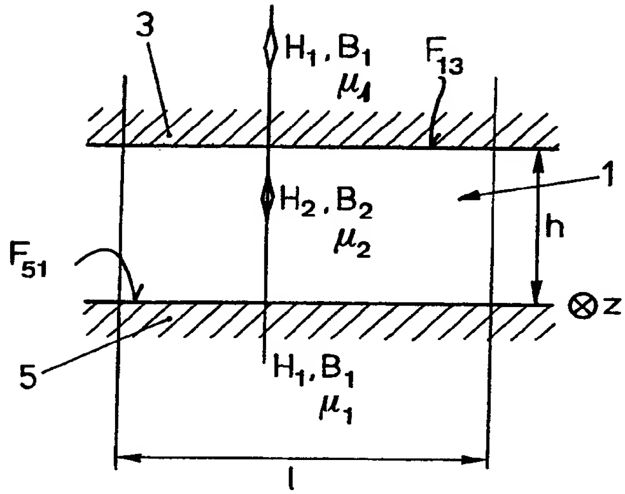
3
H_1, B_1
μ_1
F_{13}
1
H_2, B_2
μ_2
h
F_{51}
z
5
H_1, B_1
μ_1
l

FIG.1

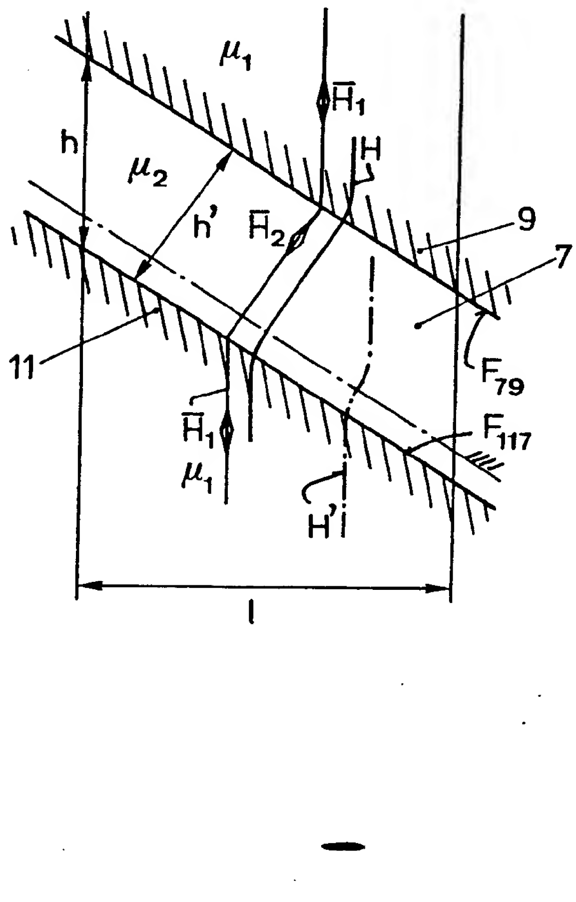
μ_1
$\overline{H}_1$
h
H
μ_2
h'
$\overline{H}_2$
9
7
11
F_{79}
$\overline{H}_1$
F_{117}
μ_1
H'
l

FIG.2

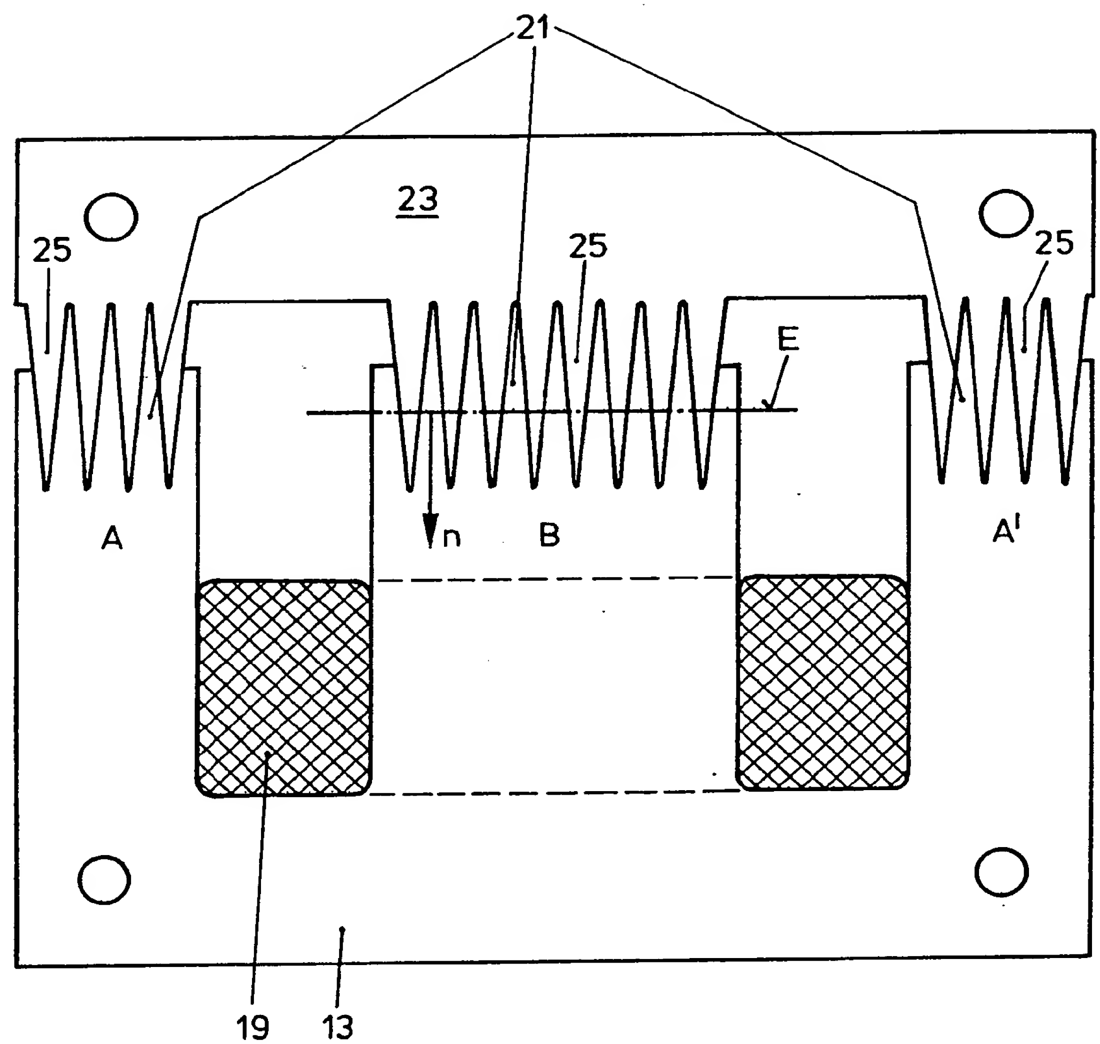

FIG.3a

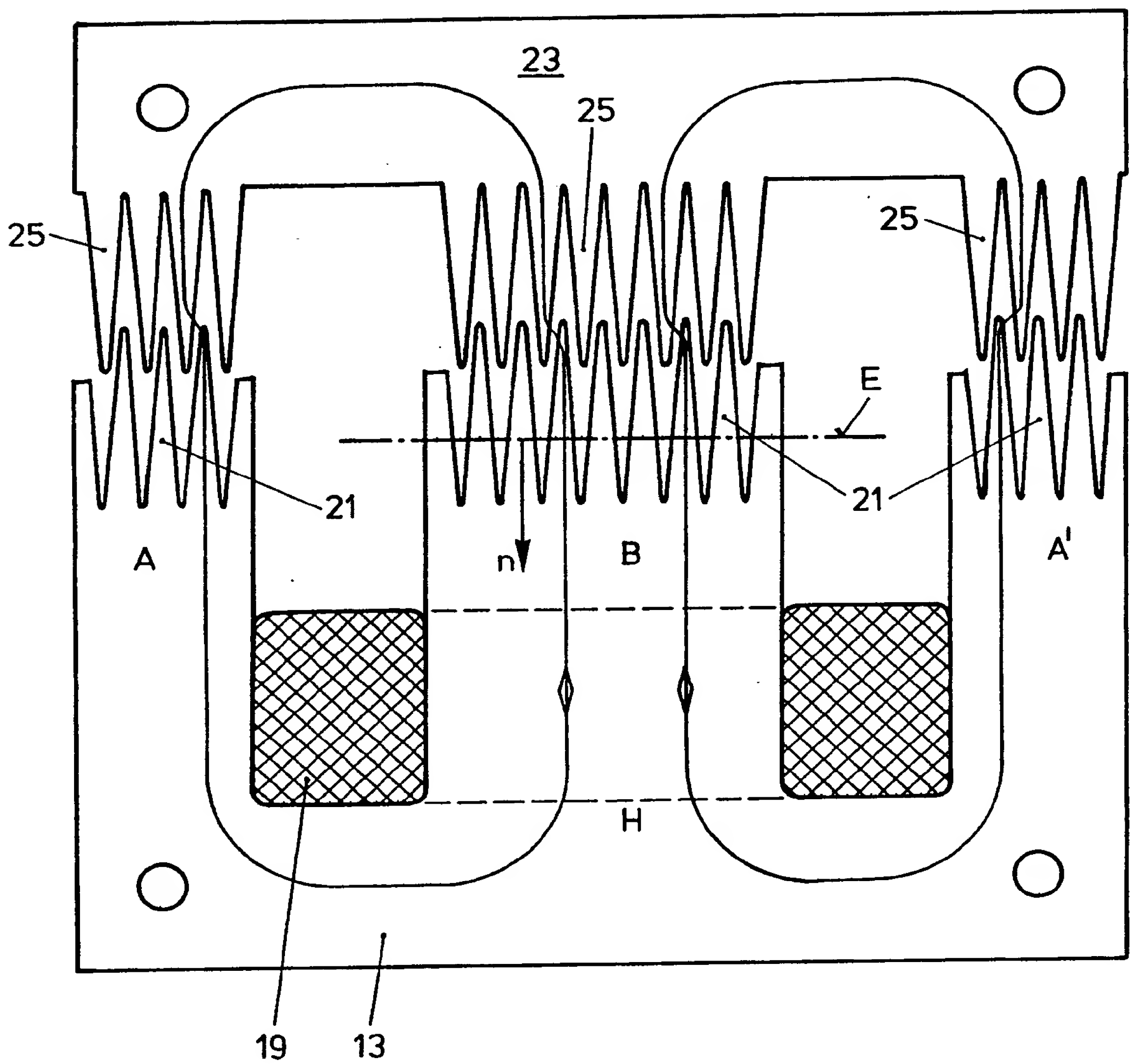

FIG. 3b

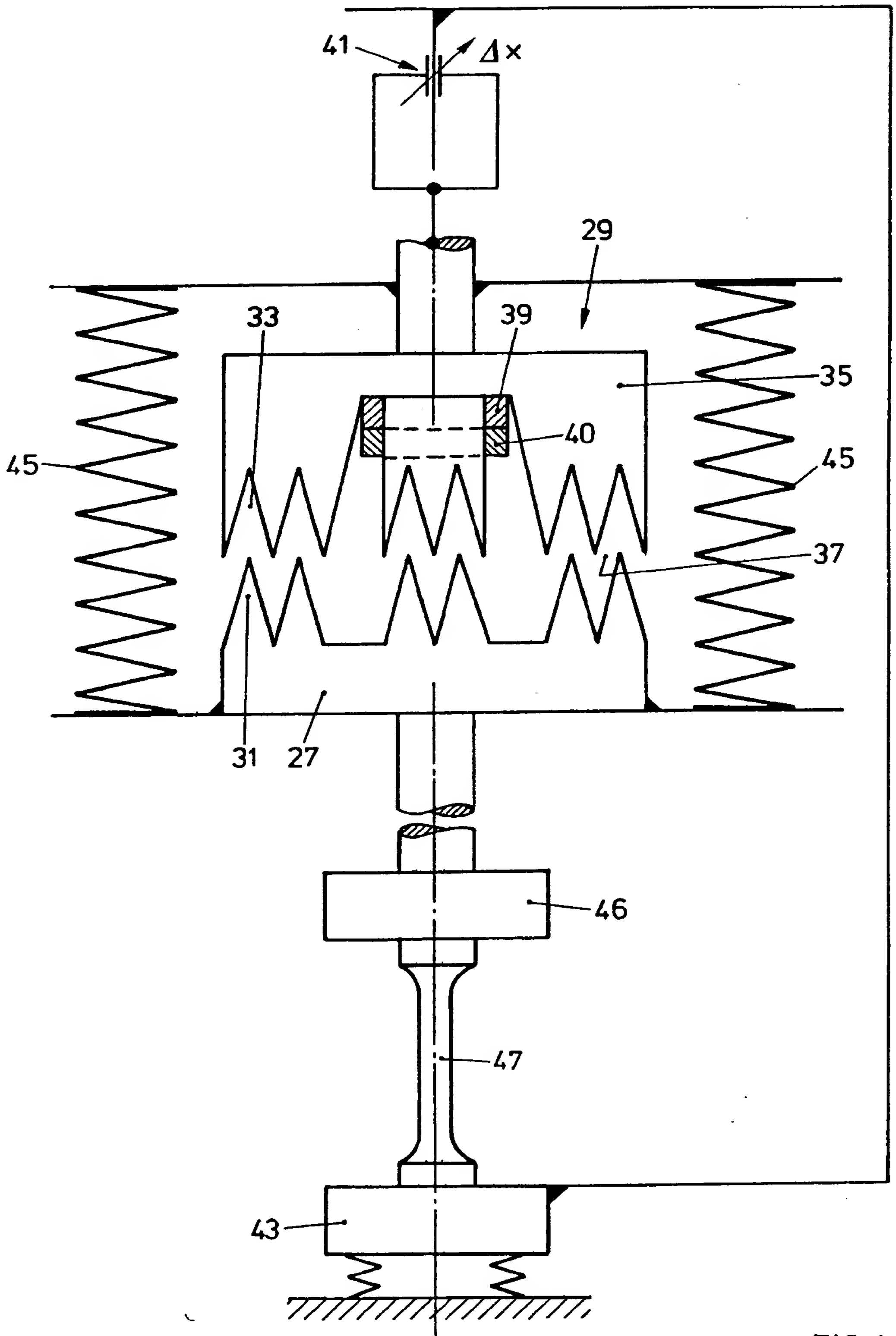

FIG.4

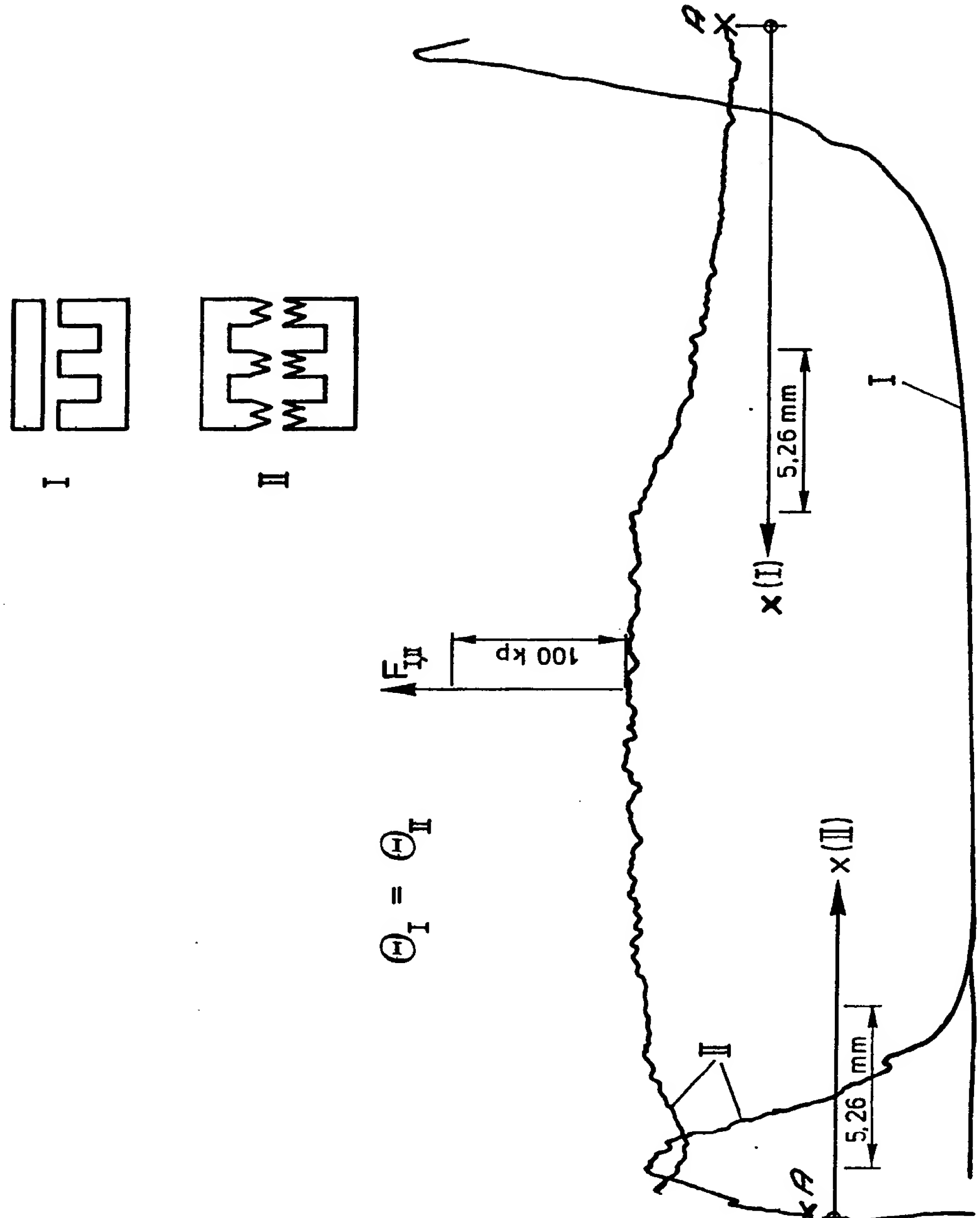

FIG.5

SPECIFICATION

Method of reducing th dep ndence f the air gap energy on gap length in a magnetic circuit and apparatus using the method

The present invention relates to a method of reducing the dependence of the magnetic air gap energy on the air gap width in two material phases kept apart by the air gap, with a magnetic field flowing across the air gap from one phase to the other and/or vice versa, as well as a device for working the method and a force generator.

It is known that magnetic devices like those with exciting coil, core, and armature can be used as force generators as for example in pulsators for materials testing. The core and exciting coil or armature are connected both to a reference system, corresponding to the armature or core and for force transmission, to a system to be subjected to force, such as a sample. It is frequently necessary under these circumstances to change the statically delivered force in the manner of a working point shift for the system subjected to alternating force, this being accomplished by elements being provided in addition to the magnetic device which determine the static load. Such elements comprise for example springs provided between the sample-associated and reference system and which are appropriately tensioned to deliver the static working point load. Since such elements in most cases do not operate with zero shift when their force is adjusted, as for example springs, can be retensioned only by executing a certain stroke from one pretensioning force to another, the air gap of the magnetic circuit is also altered thereby, unless precautions are taken by means of which the width of the air gap can be reset to its specified size without affecting the spring travel at the same time. Changes in the width of the air gap, through changes in volume for a preset magnetic field, cause changes in the magnetic energy in the air gap and consequently also changes for example in the force generated in a predetermined field. A typical example in which these problems occur is the above-mentioned pulsators. Usually they have a core with an exciting winding connected to a reference system. An armature is provided, separated axially from the core in the stress direction for a sample, said armature being connectable with the sample. Springs are provided between the reference system with one magnetic circuit part and with the part of the system connected with the sample, with the aid of which springs the static pretensioning is applied to the sample. By changing this preset value, the spring compression is changed and therefore initially the air gap between the parts of the magnetic circuit which are separated by the air gap. Therefore, known pulsators have an adjusting device which renders one of the parts of the magnetic circuit displaceably positionable relative to the stress application direction without shifting the bearing and counterbearing of the springs at the same time. In this way the change in the air gap caused by the compression of the spring can be compensated. It is understood of course that such an adjustment after pretensioning changes have been made is extraordinarily delicate and must be performed with the utmost precision. It is not possible simply to change the static load during alternating stress testing.

The goal of the present invention is to ensure that the change caused by changes in the air gap in the magnetic energy in the air gap is reduced in such fashion that, for example in systems like the above-mentioned pulsators, a change in the width of the air gap caused by a change in the static load does not make it necessary to readjust the width of the air gap, because the change in the width of the air gap produces practically no change in the magnetic air gap energy, with a predetermined field, so that a predetermined force application, for example as a test criterion, can be accepted unchanged even with new air gap width values, without changing the field.

For this purpose, the method cited at the outset is characterized by the fact that at least one segment of the air gap marginal area is exposed to at least one phase in such fashion that the field in the air gap is refracted with respect to the other in this phase.

The expression "refract" by analogy to optics, is understood to refer to the change in field direction at the interface between the materials with different permeabilites.

As will be rendered understandable below and has been surprisingly well confirmed experimentally, apparently by providing a field refraction between one phase and the air gap on the one hand and/or an air gap and the other phase on the other hand, an energy density is produced in the air gap which is a function of the width of the air gap, said en rgy density largely compensating volume-influenced energy changes in air gap width changes. It has already been mentioned above that the r fraction-produced change in the field en rgy density in th air gap is manifested in accordance with the laws of refraction in the air gap with a relatively wide air gap. This refraction and its nergy d nsity r ducing effect with decr asing gap width become increasingly less significant, i.e., energy density increases with decreasing gap width and counteracts the loss of air gap energy by the decreasing air gap volume.

A device for working the above method with two parts separated by an air gap, with a magnetic field being applicable from one part to the other through the air gap, is characterized

by the fact that the air gap is delimited at least partially by at least one area segment on one and/or the other part, said segment being at an oblique angle relative to the path of the field in one and/or th other part in the area abutting the air gap.

An area segment thus disposed satisfies the refraction condition wherein the field, on leaving one part, does not strike the segment of the air gap marginal area perpendicularly.

By changes in the tangential and normal components of the field corresponding to permeability, the magnetic and induction field, relative to its area segment, the change in direction of the path of the field on crossing from one part into the air gap and perhaps back into the second part, whereby however according to the invention the reactive effect of the one part on the refraction at the marginal area of the other part, increasingly pronounced with decreasing air gap width, is utilized.

The efficiency of a magnetic circuit of this type is kept as high as possible by virtue of the fact that at least one exciter coil is provided, and has a coaxial core part, whereby an air gap marginal area on the core part side lies at least nearly completely outside the core part surrounding the coil.

For operation at higher frequencies, up to 500 Hz for example, it is further proposed that one or the other part of the magnetic circuit be formed at least in large part of laminated sheet metal.

A force generator for a pulsator to generate a force on a sample with an electromagnetic device composed of two magnetic circuit parts separated by an air gap traversed generally in the force direction by a magnetic field is characterized by the fact that the air gap marginal area of at least one of the parts has at least one segment which is at an oblique angle to the field direction in the part in the air gap marginal area.

Preferably the marginal areas of both parts are provided with complementary intermeshing teeth to form such segments.

The invention will now be described for example with reference to the figures.

Figure 1 is an air gap volume element, through which a field flows without refraction, for calculating the field energy;

Figure 2 is a representation similar to Fig. 1 of an air gap volume segment through which a refracted magnetic field is flowing, for calculating the field energy relationships created therein;

Figures 3a and b each show a side view of an electromagnetic device according to the invention, with different gap widths;

Figure 4 is a schematic representation of a pulsator like that used for materials testing, with a force unit according to the invention;

Figure 5 shows an air gap width/force diagram to illustrate the difference between a device according to Fig. 3 with a flat air gap margin as in Fig. 1 and one with an air gap as shown in Fig. 3, i.e. according to Fig. 2.

Fig. 1 shows a volume element V of an air gap 1 between two material phases 3 and 5. Magnetic field H flows through both material phases as well as their areas immediately adjacent to air gap 1, and the air gap. If material phases 3 and 5 are the same, the field can be represented by H_1 and the induction field by B_1 in both. in this volume element with length 1 and height h, with a length perpendicular to the plane of the Fig. z, the magnetic energy W is:

$$2W_v = \mu_0 \cdot \frac{\mu_1{}^2}{\mu_2} H_1^2 \cdot 1 \cdot h \cdot z \qquad (1)$$

taking into account the fact that magnetic induction $\bar{B}$ always passes through interfaces F_{51}, F_{13}, while magnetic field $\bar{H}$ corresponding to the ratio of the air gap permeability μ_2 and the permeability of material phases 3 and 5, μ_1 undergoes a value discontinuity at the interfaces.

Fig. 2 likewise shows an air gap volume element 7 between material phases 9 and 11 of the same material as those in Fig. 1. The horizontal extent of the volume element is again equal to 1, while the air gap width is selected to be the minimum distance between marginal areas, h', equal to air gap width h in Fig. 1. The field curve $\bar{H}_1$, $\bar{H}_2$, $\bar{H}_1$ is qualitatively used to show the refraction of the magnetic field at interfaces F_{117}, F_{79} between material phases 11, 7 on the one hand and 7, 9 on the other. For these ratios, the magnetic energy in the air gap is

$$2W_v = \{H_1^2 \mu_0 \frac{\mu_1{}^2}{\mu_2} \cos^2\alpha + \mu_0\mu_2 \sin^2\alpha\} \cdot 1 \cdot h \cdot z \qquad (2)$$

where h, in contrast to gap width h', represents the vertical extent of the air gap. It is apparent from a comparison of (1) and (2) that the magnetic air gap energy, taking particularly into account the fact that an iron material is usually chosen as the material phas , with high permeability μ_1, in the field refraction case with equal gap volume as $\cos^2\alpha$ is less than in the

case in which according to Fig. 1 th field penetrates unrefracted through the air gap. To evaluate the energy changes with volume or field changes, however, the energy contribution is of no significanc . It is also evident from (1) and (2) that in both cases the field energy density, apart from volumes $1 \cdot h \cdot z$ on the right hand side of the equation, is independent of the gap width. Thus, from this theoretical viewpoint, the phenomenon upon which the invention is presumbably based, is not yet explicable. It is essential to recall that the path of the field does not run as marked in Fig. 2 with $\bar{H}_1$, $\bar{H}_2$, $\bar{H}_1$ but initially as qualitatively shown by curve H. If the air gap width h or h′ is reduced for example to the dimension represented by the dot-dashed lines, then as shown at H′, the field curve increasingly shifts to the refracted field curve as shown in Fig. 1, i.e. the refraction in the remaining air gap becomes increasingly insignificant. From this it is evident that the field energy density according to (2) with decreasing air gap becomes a function of air gap width and increases against the energy density value according to (1), namely for $h \rightarrow 0$. It is therefore evident from (2) that as the air gap volume decreases and therefore the air gap energy initially decreases, the magnetic energy density in the air gap increases so that the energy decrease caused by the volume decrease in the air gap will be compensated by an increase in the magnetic energy density. This explains why, when an air gap is provided, the magnetic field is refracted at its marginal area and a smaller air gap width dependence of the magnetic energy in the air gap is achieved than in a device according to Fig. 1, in which the magnetic field penetrates unrefracted through the air gap.

A more general examination may make the invention more plausible. With a homogeneous field distribution in the gap the magnetic air gap energy can be written as follows.

$$W = w(x, H) \cdot V(x),$$

where x represents the air gap width and w the energy density

$\frac{\bar{B} \cdot \bar{H}}{2}$ where B is the induction field.

For a general force we will have

$$dW = \frac{\delta W}{\delta x} dx + \frac{\delta W}{\delta H} dH$$

$$= \left[\frac{\delta w}{\delta x} \cdot V + \frac{\delta V}{\delta x} \cdot w\right]_{H=\mathrm{konst}} dx + \left[\frac{\delta w}{\delta H} \cdot V + \frac{\delta V}{\delta H} \cdot w\right]_{x=\mathrm{konst}} dH$$

where: $\frac{\delta V}{\delta H} = o.$

Then in the case of the relationship in Fig. 1:

$$\frac{\delta w}{\delta x} \equiv o,$$

which for this case leads to:

$$dW = \frac{\delta V}{\delta x} w dx + \frac{\delta w}{\delta H} V dH$$

As we have shown, in the cas of Fig. 2

$$\frac{\delta w}{\delta x} \neq o, \quad \frac{\delta w}{\delta x} < o$$

which then leads to

$$dW = \left[\frac{\delta w}{\delta x} V + \frac{\delta V}{\delta x} w\right] dx + \frac{\delta w}{\delta H} VdH$$

$$\text{sign} \frac{\delta w}{\delta x} = - \text{sign} \frac{\delta V}{\delta x} \text{ indem } \frac{\delta V}{\delta x} > o$$

we can see that

$$\underline{\text{Fig. 1}} \qquad \underline{\text{Fig. 2}}$$

$$\frac{\delta V}{\delta x} Vdx > \left[\frac{\delta w}{\delta x} V + \frac{\delta V}{\delta x} w\right] dx$$

from which it is plausible that the change in air gap energy during field refraction is less dependent upon air gap volume changes than without field refraction. With only a slight (in the ideal case, nonexistent) dependence between air gap width and magnetic air gap energy, the energy relationships change little if at all when the air gap width is changed, and field-dependent energy changes are at least nearly independent of the set air gap width.

In Figs. 3a and b the example of a design for a magnetic device according to the method of the invention is shown. A core 13, especially for generating alternating stresses, as for example up to 500 Hz, made of cross-laminated sheet metal, is designed as a E-core. Its middle leg is surrounded by an exciting winding 19. Its magnetic poles A, B, and A' have tooth-shaped areas 21 as shown, transversely to the sheet metal lamination direction. Tooth 21 however can also be provided lengthwise to the lamination direction depending on the advantages and disadvantages of manufacturing. All three legs of the E have these teeth 21. The number of teeth 21 and the choice of where they should be provided depend on the intended application of the magnetic device as well as experimental results. For reasons of optimization of efficiency, teeth 21 do not penetrate winding 19, especially on middle leg B. The magnetic device also has an armature 23, especially in the above-mentioned case, preferably likewise made of laminated sheet metal, which has teeth 25 complementary to teeth 21 on the core, in such fashion that it can be slid into core teeth 21 while maintaining an air gap width. In this fashion, the necessary conditions for field refraction in the air gap are created. In the diagram the path of the field with refraction is indicated at H. Preferably the teeth on core 13 and on armature 23 with respect to the basic area extent of the air gap corresponding to plane E are arranged symmetrically to normals n to plane E, so that it is then possible in certain cases to deviate from this symmetry, for example in cases when the left and right toothed legs of the core and armature have air gap widths of different sizes between them.

Fig. 4 shows a schematic diagram of a pulsator with a force generator designed according to the invention. Toothed armature 27 of force generator 29 according to the invention has its teeth 31 engaging the matching teeth 33 of a core 35. Air gap 37 is defined between the complementary core and armature teeth. The core with the exciting winding 39 shown schematically and pre-magnetization winding 40 is lockable; however, as shown in Fig. 41 schematically, it is axially displaceable through Δx relative to a base weight 43, with a spring support. Pretensioning springs 45 are located between the core 35 and armature 27. By shifting core 35 with armature 27 provided with a counterbearing through an exciting weight 46 on a sample 47, the tension of springs 45 is adjusted to adjust the static pretensioning for sample 47 which otherwise rests on base weight 43. The resultant change in the air gap width or the air gap volume does not cause any air gap width compensation, so that for example armature 27 must subsequently be shifted, but, with the precautions according to the invention, even after the air gap width is changed work can continue with the designated current values on exciting winding 39 and pre-magnetization winding 40 and hence with the designated through flow.

In Fig. 5 the measured dependence of static magnetic force F is shown at I for a conventional magnetic arrangement with flat poles according to Fig. 1, with reference to gap width x. II shows this dependence of a magnetic device as in Fig. 1 but with pole teeth according to the invention with the same through flow θ. The constancy of force F_{II} across a v ry broad air gap range of about 1.5 mm to nearly 40 mm is striking.

CLAIMS

1. M thod of reducing the dependence of the magnetic air gap nergy (W) on air gap width (h) with two material phases (3, 5, 11, 9), maintained at a distance across the air gap, whereby a magnetic field (H) flows across air gap (1, 7) from one phase to the other and/or vice versa, characterized by the fact that at least one segment of the air gap marginal area is exposed to

one phase in such fashion that the field is refracted in air gap (H_2) relative to that in this phase (H_1).

2. Device for working the method according to Claim1 with two parts (9, 11, 13, 23, 27, 35) separated by an air gap, whereby the magnetic field (H) is applicable from one part to the other through the air gap (7, 37), characterized by the fact that the air gap is delimited at least partially by at least one area segment (21, 25, 31, 33) on one and/or the other part, which is mounted at an oblique angle relative to the path of the field in one part or the other (23, 13, 27, 35) in the area abutting the air gap.

3. Device according to at least one of the claims as in Claim 2, characterized by the fact that the path of the field in one part or the other in the air gap area runs at least nearly perpendicularly to the area extent (E) of the air gap, and by the fact that the area segments project inward or outward at oblique angles relative to area extent (E).

4. Device according to at least one of the claims, as according to one of Claims 2 or 3, characterized by the fact that the marginal area of at least one part is provided with teeth that form the area segments toward the air gap.

5. Device according to at least one of the claims, as according to Claim 4, characterized by the fact that the marginal areas of the two parts are provided with complementary teeth meshing with one another.

6. Device according to one of Claims 2 to 5, characterized by the fact that one part is designed as an exciting coil core device, and the other part closes the magnetic circuit through the air gap.

7. Device according to at least one of the claims, as according to Claim 6, characterized by the fact that at least one exciter coil is provided with a coaxial core part, whereby an air gap marginal area on the core part side is at least nearly completely located outside the core part surrounding the coil.

8. Device according to at least one of the claims, characterized by the fact that one part or the other is formed at least in large part of laminated sheet metal.

9. Force generator for a material testing pulsator for generating a testing force on a sample with an electromagnetic device composed of two magnetic circuit parts separated by an air gap traversed generally in the force direction by a magnetic field, characterized by the fact that the air gap marginal area of at least one of the parts (27, 35) has at least one segment which is at an oblique angle to the field direction in the part, in the area abutting the air gap.

10. Force generator according to Claim 9, characterized by the fact that the marginal areas of both parts have complementary intermeshing teeth to form segments.

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